On the scientific utility of surface-based liquid water path measurements in marine stratus

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1. Introduction

The accurate elucidation of the myriad ways in which boundary-layer marine clouds influence climate, as well as a deeper understanding of the underlying cloud processes through data analysis, is to a large degree influenced by how well the cloud liquid water paths (LWPs) can be known. Examples include the quantification of cloud radiative impacts both plane-parallel and three-dimensional, aerosol indirect effects, and the development of useful cloud parameterizations. The latter often invoke the assumption that adiabatic quantities are well-mixed with height, implying that testing for the limits of the adiabatic assumption by comparing retrieved LWPs to those from an adiabatic ascent calculation is also useful.

Satellite microwave liquid water path measurements, even in regions lacking upper-level ice clouds, are subject to uncertainties introduced by an angle-dependent polarized reflecting surface (i.e. ocean waves) and by incompletely-filled footprints. Even at best, the spatial resolution is on the order of 30 km (e.g., SSMI). Surface-based LWP measurements in theory provide the best available measurements. As indicated through a number of recent papers (for examples, see proceeding from ARM meetings), however, establishing a high accuracy requires care.

In this poster we examine LWPs retrieved from surface-based microwave radiometer measurements collected on the R/V Ron Brown during the Eastern Pacific Investigation of Climate experiment, held during the fall of 2001 within the southeastern Pacific stratus region, off of the coast of Peru. The goal is to initially establish that the derived LWPs are reasonably accurate, and then examine the limits of the adiabatic assumption, the relationship of the LWPs to drizzle, and (in future work) the influence of instrument noise upon the accuracy of the LWPs. This poster presents preliminary work.

2. Data

Two microwave radiometers were on board the R/V Ron Brown, one with channels at 20.6 and 31.65 Ghz (referred to as the "ETL" radiometer here), and a "mailbox" radiometer similar to what is in use at ARM sites with channels at 23.8 and 31.4 Ghz. 9 clear-sky soundings coincident with the ETL radiometer data exist, and the 20.6 and 31.65 Ghz brightness temperatures compare satisfactorily (Fig. 1).

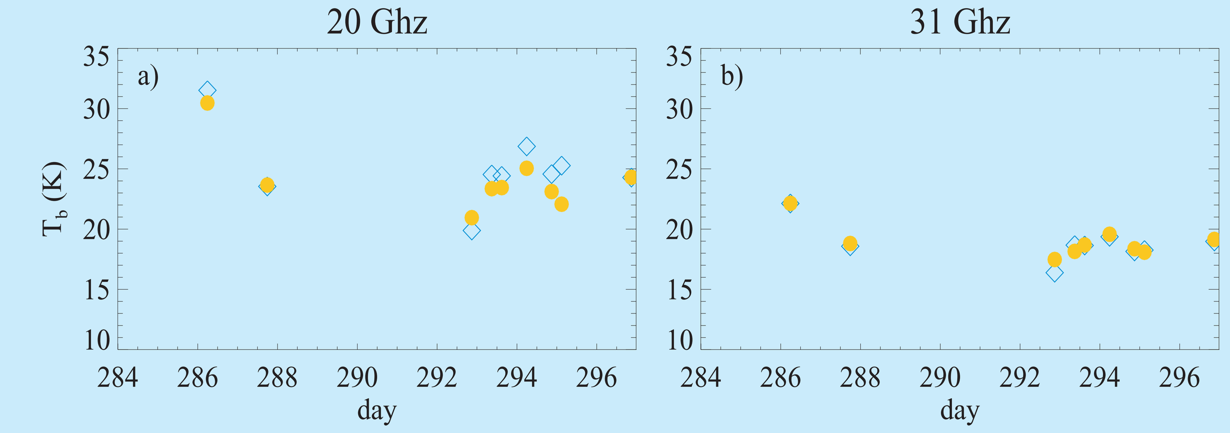


Fig. 1: a) 20.6 Ghz brightness temperatures calculated from clear-sky soundings (blue diamonds) and coincident ETL radiometer measurements (yellow filled circles). b) same but for 31.65 Ghz brightness temps.

The mailbox 23 Ghz brightness temperatures (Tbs) compare well to the ETL 20 Ghz brightness temperatures, but the two respective 31 Ghz Tbs compare poorly (Fig. 2). At low brightness temperatures most of the mailbox 31 Ghz Tbs are about 2 K higher than the ETL 31 Ghz Tbs, while the opposite often holds true at the higher brightness temperatures. The two variables should fall more closely to the y=x line, and relate linearly to each other. Relationships over shorter time periods are more consistent, suggesting that the cause is the application of different (automatic) calibrations at different times. The relationship was generally close until JD=292, but noisy thereafter.

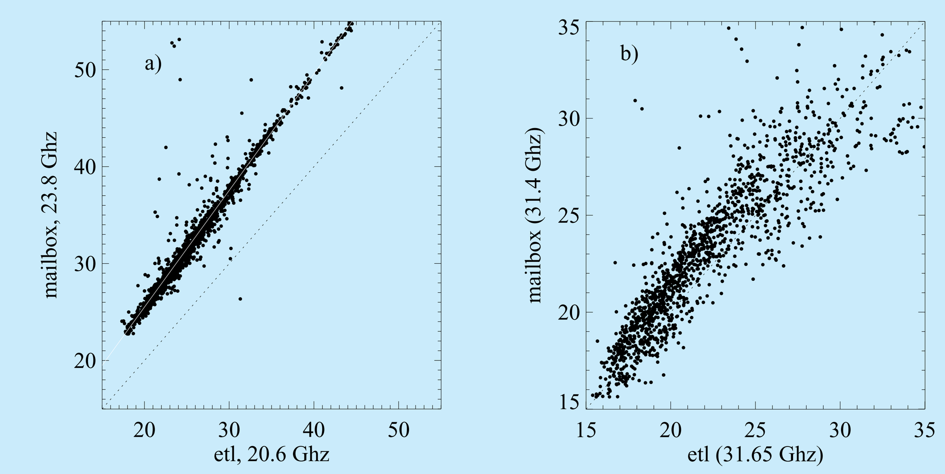


Fig. 2:a) mailbox 23.8 Ghz measured Tbs vs. ETL 20.6 Ghz Tbs. b) Mailbox 31.4 Ghz Tbs vs. ETL 31.65 Tb. Both at 10 min. resolution

3. Retrieval

We preferred the ETL radiometer data when it was available, and utilized corrected mailbox radiometer data for those times when the ETL radiometer was not working properly (JD 289.5-292, parts of JD 286 and 296). Mailbox LWP values were corrected using regressions based on coincident ETL LWP measurements (Fig. 3a andb), or, used the mean difference between the two datasets (Fig. 3c).

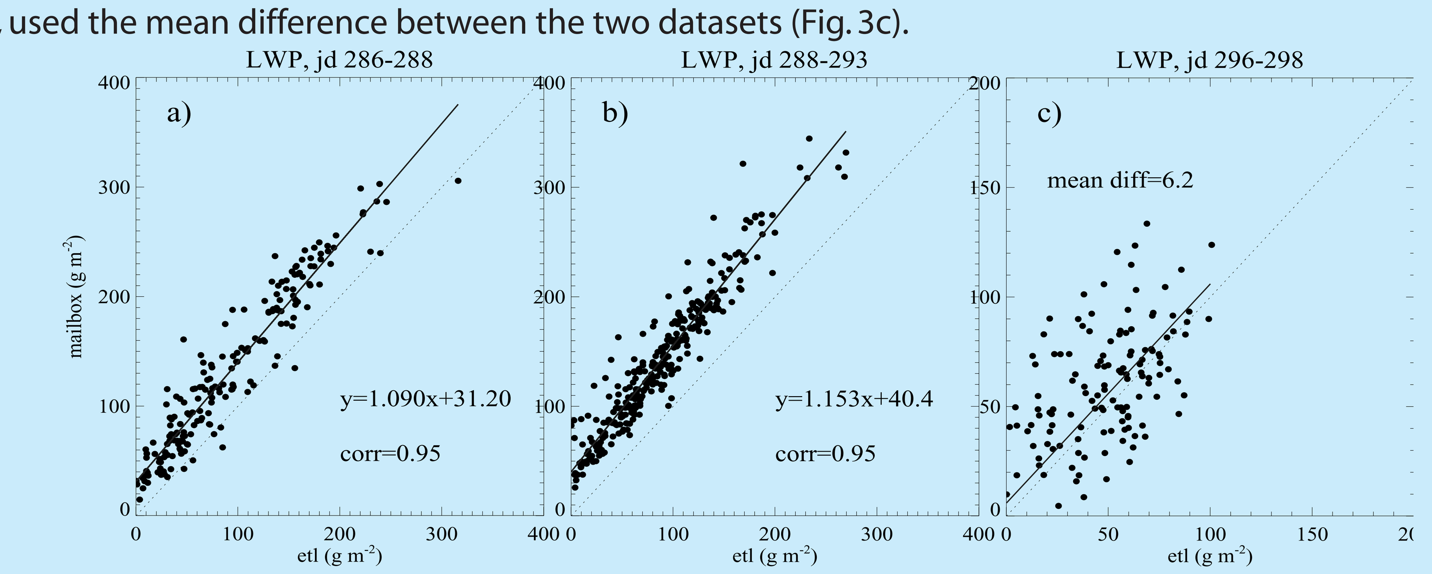


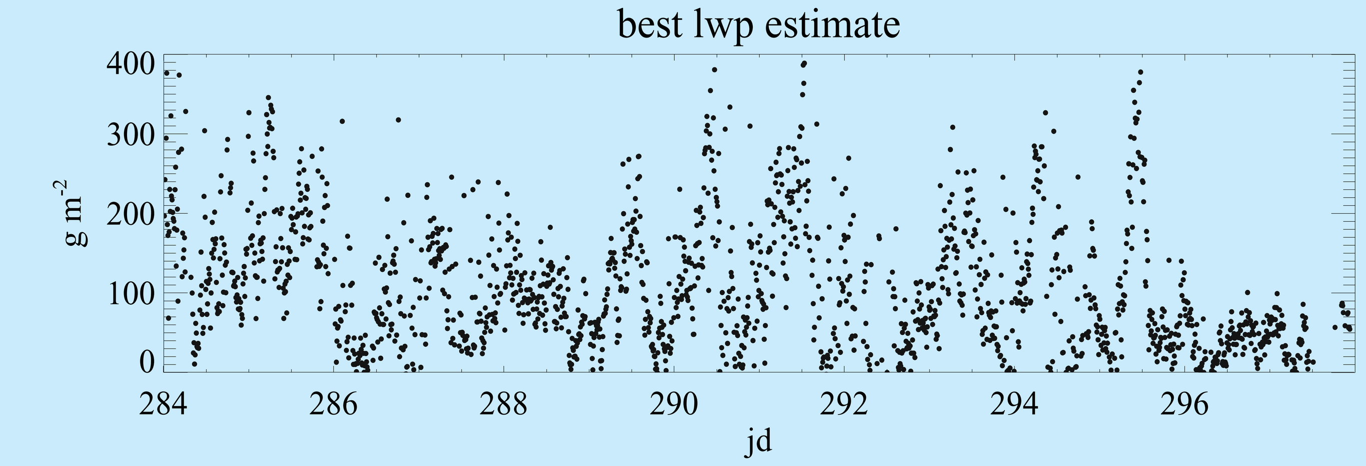
Fig. 3: Liquid water paths retrieved from the mailbox radiometer versus those retrieved from the ETL radiometer for a) JD 286-288, b) JD288-293, c) JD 296-298.

The LWP retrieval itself searches for the LWP value that minimizes the function

$$F = |\, Tb\{20Ghz,calc\} - Tb\{20Ghz,meas\} \,| + |\, Tb\{31Ghz,calc\} - Tb\{31Ghz,meas\} \,|$$

where LWP is the only independent variable and the water vapor path is an input specified from an interpolated sounding. The sondes utilized during EPIC were of type Vaisala RS-80, of recent manufacture, and should produce fairly accurate WVPs. The retrieval iterates in liquid water amount, inserting liquid water between the ceilometer-derived cloud base and radar-determined cloud top (constrained to not exceed 1700 m). The 20 Ghz channel is primarily sensitive to the WVP, and the 31 Ghz channel to the liquid, so that in practice, using the sonde-derived WVP as an input reduces the minimization of F to primarily a single-frequency minimization. We used the Liebe 1987 water vapor line and continuum absorption mode., Rosenkranz-Liebe 1988 molecular oxygen line absorption and dry air continuum absorption, and Liebe 1993 liquid water droplet absorption. The LIebe 1987 model is thought to perform well for the water vapor paths typical of the EPIC stratus region (Marchand et al., 2003).

A time series of the best current estimate of the EPIC 2001 stratus liquid water paths is shown in Fig. 4. If we assume the absorption models are appropriate, we can estimate a LWP uncertainty of 15 g/m^2 from an instrument measurement error of 0.5 K in the brightness temperatuer.



4. Relationship to adiabatic values

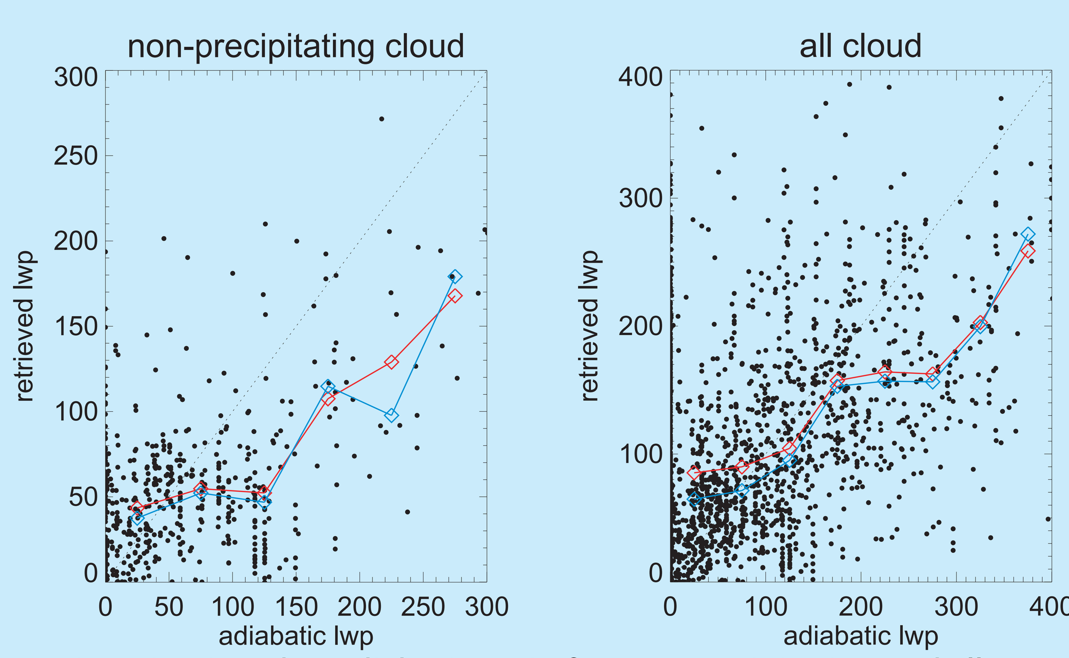


Fig. 5: Retrieved vs adiabatic LWPs for non-precipitating and all cloudy columns, in units of g/m^2. The red and blue lines indicate the mean and median retrieved LWPs occurring within 50 g/m^2 bins of the adiabatic LWPs, respectively.

Liquid water paths calculated from an adiabatic ascent beginning at the ceilometer-determined cloud base and using the temperature and humidity structure interpolated from nearest-in-time rawindsondes, are compared to the retrieved values. Precipitation is identified by cloud radar reflectivities exceeding a threshold of -17 dBZ within coincident data (for further description, see Bretherton et al., 2004).

As shown in Fig. 5, at low liquid water paths (<~ 50g/m^2) clouds are most likely to be near-adiabatic, while at LWPs exceeding 100 gm/^2, retrieved LWPs are approximately 60% of adiabatic. This comparison still needs to consider the impact of error in the ceilometer-determined cloud base height upon the adiabatic calculation, however.

5. Relationship to drizzle

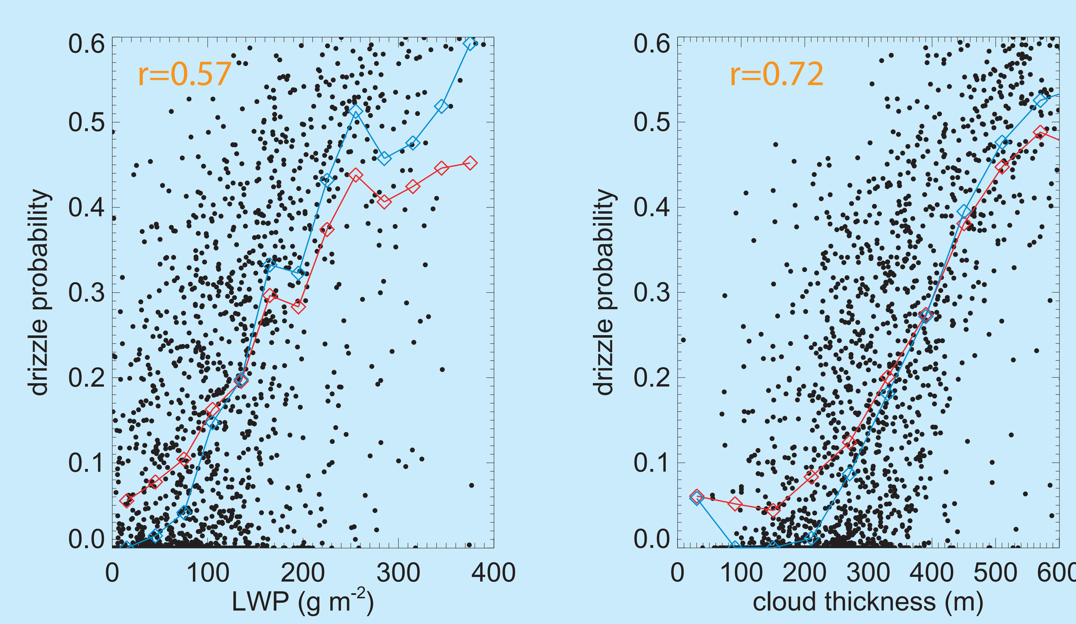


Fig. 6: Drizzle probability, calculated as the fraction of cloud radar pixels with reflectivities exceeding -17 dBZ, versus retrieved LWP (left panel) and versus cloud thickness (right panel). Red and blue lines indicate mean and median values associated with bins of 30 g/m^2 in LWP, and 60 m in cloud thickness.

At what LWP does drizzle become a significant cloud feature ? As shown in Fig. 6a, the probability of light-drizzle is about 25% at a LWP of 150 g/m^2 (in the mean) and reaches a median probability of 50% at a LWP value of 250 g/m^2. The probability of significant drizzle, as indicated through a more stringent radar reflectivity threshold of 0 dBZ, is much lower, only reaching 10% at a LWP value of 320 g/m^2 (not shown). Interestingly, a higher correlation is seen between cloud thickness and the probability of light drizzle, than between LWP and drizzle (Fig. 6b).

6. Further Work

The retrieved LWPs presented here correspond to a 10-minute average. Cloud processes can occur at much smaller time scales, for example, the response of cloud particle size to aerosol within updrafts (e.g, Feingold et al., 2003) , or, the depletion of LWP by drizzle. LWP retrievals at the time scale of the original data (15 sec) will be done and spectrally evaluated, to assess their utility in addressing these questions.

References:

Marchand, R., T. P. Ackerman, E. Westwater, S. Clough, K. Cady-Pereira, and J. Liljegren, 2003: An assessment of microwave absorption models and retrievals of cloud liquid water using clear-sky data. J. Geophys, 108, doi: 10.1029/2003JD003843.

Bretherton, C., T. Uttal, C. Fairall, S. Yuter, R. Weller, D. Baumgardner, K. Comstock, R. Wood, and G. Raga, 2004: The EPIC 2001 stratocumulus study. Bull. Amer. Meteor. Soc.,85,967-977.

Feingold, G., W. Eberhard, D. Veron, M. Previdi, 2003: First measurements of the Twomey indirect effect using ground-based remote sensors. J. Geophys. Res., 30, doi: 10.1029/2002GL016633.